Magnetic field strength in a short coil as a function of radius

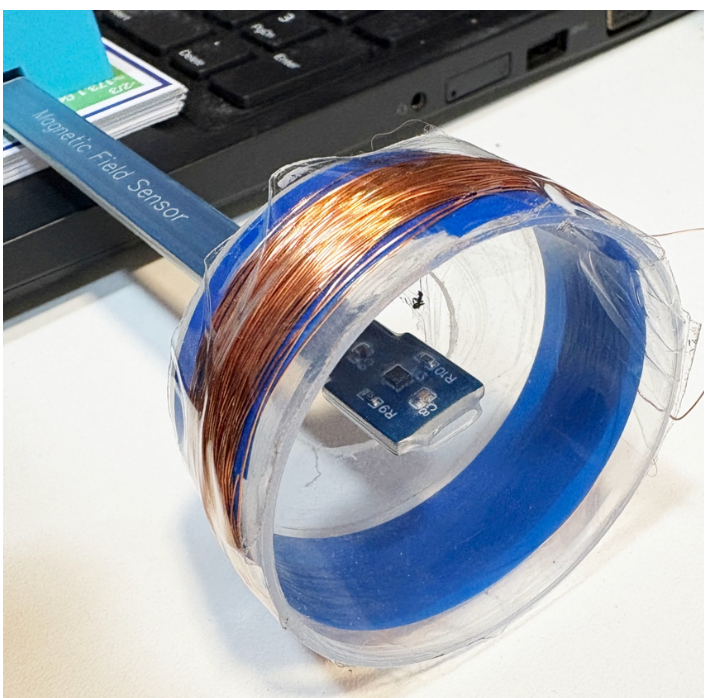
Richard Walding - 19 November 2024

As another modification of an experiment on the magnetic field strength about a current-carrying wire or solenoid, I tested how the field strength varies with radius of a "short coil". Unlike a solenoid where L>>d, a short coil is one where L<<d. On page 214 of the Oxford U3&4 text I posed a Challenge comparing the different formulas for a solenoid ($B = \mu_0 nI$) and a loop. The short coil formula is $B_{\text{short coil}} = N\dfrac{\mu_0 I}{2R}$.

I wanted to see if B was proportional to $\dfrac{1}{2R}$ for a short coil, where $2R$ is the diameter of the coil. I also wanted to test the accuracy of the formula against the experimental data in the determination of μ_0 – the permeability.

SETUP

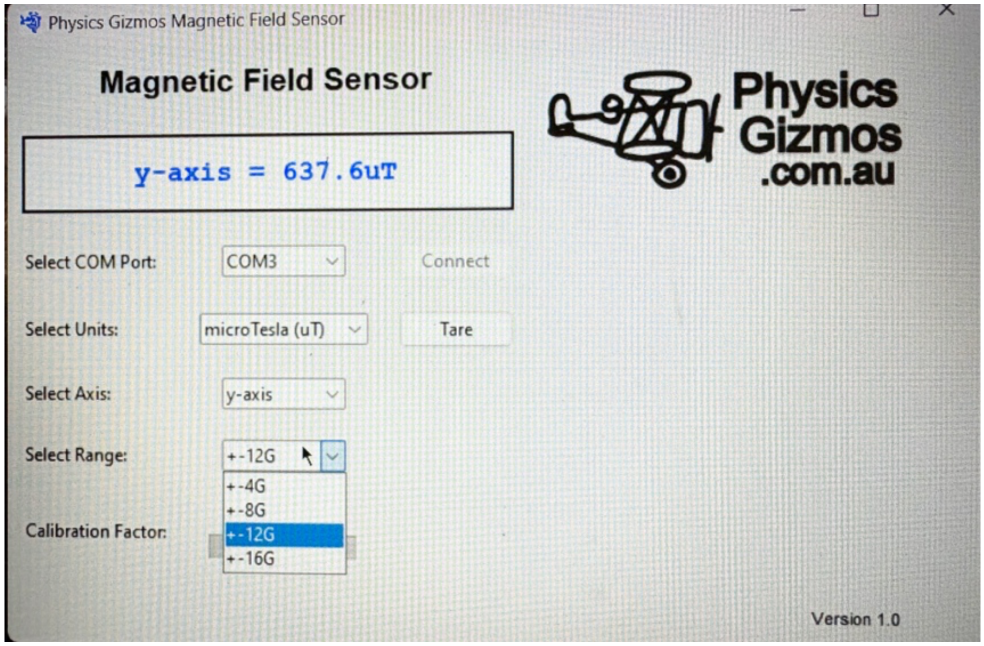
I made up six coils by wrapping 70 turns of enamelled wire around plastic tubes of different diameters.



The magnetometer sensor oriented along the y-axis parallel to the field. This is Ian Thompson's *Magnetic Field Sensor* (physicsgizmos.com.au). They cost about $75.

I used 0.25 mm diameter (33AWG) enamel copper wire from Jaycar ($8.95 for 58 m spool)

Regulated power supply set to a current of 0.400 A



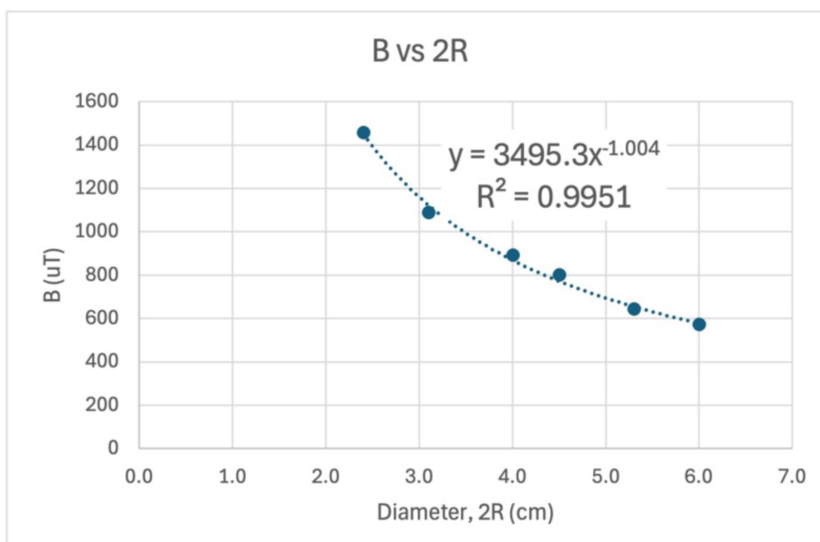
Screenshot of reading for 5.3 cm (2R = 5.3 cm) diameter coil

RESULTS

I only did one trial to test this out but there was hardly any variation in the results, so I didn't bother. Because we expect a non-linear relationship, I would suggest 7 variations of R and three replicates for each (7 × 3). Students need to justify why they have chosen a certain number of variations of the IV and the number of replicates. If they say 5 × 3 or whatever they should say why.

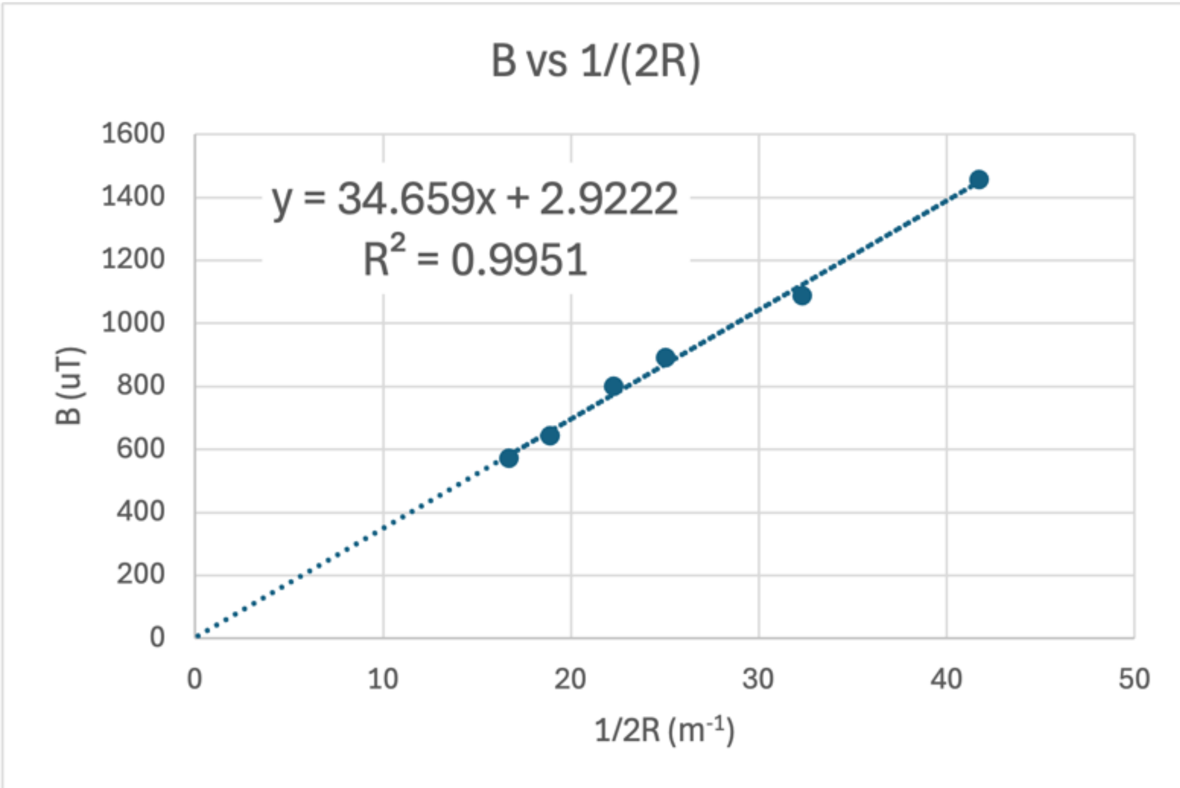
The equation for the line suggests the relationship is inverse: $B \propto \frac{1}{2R}$

2R (cm)	2R (m)	1/2R (m^{-1})	B (μT)
2.4	0.024	42	1456
3.1	0.031	32	1088
4.0	0.040	25	890
4.5	0.045	22	800
5.3	0.053	19	643
6.0	0.060	17	571



LINEARISED

To linearise, I plotted B vs 1/(2R), that is, B vs 1/diameter.



It linearised well and gave an R^2 value of 0.9951 which was very pleasing. Probably the most straightforward thing to compare is the experimental and accepted values of μ_0

$$gradient = \frac{B}{\frac{1}{2R}} = B \times 2R = N\mu_0 I$$

$$\mu_0 = \frac{gradient}{NI}$$

$$= \frac{34.659 \times 10^{-6}}{70 \times 0.400}$$

$$= 1.238 \times 10^{-6}\ \mathrm{TmA^{-1}}$$

$$E\% = \frac{\left|1.238 \times 10^{-6} - 1.257 \times 10^{-6}\right|}{1.257 \times 10^{-6}} \times 100$$

$$= 1.5\%$$

SUMMARY

This would make a great student experiment and although it takes a while to make up the coils, the data collection is over in no time. I must congratulate Ian on producing such an easy-to-use magnetometer that is very stable – and cheap.

All-in-all a great result.

Cheers

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